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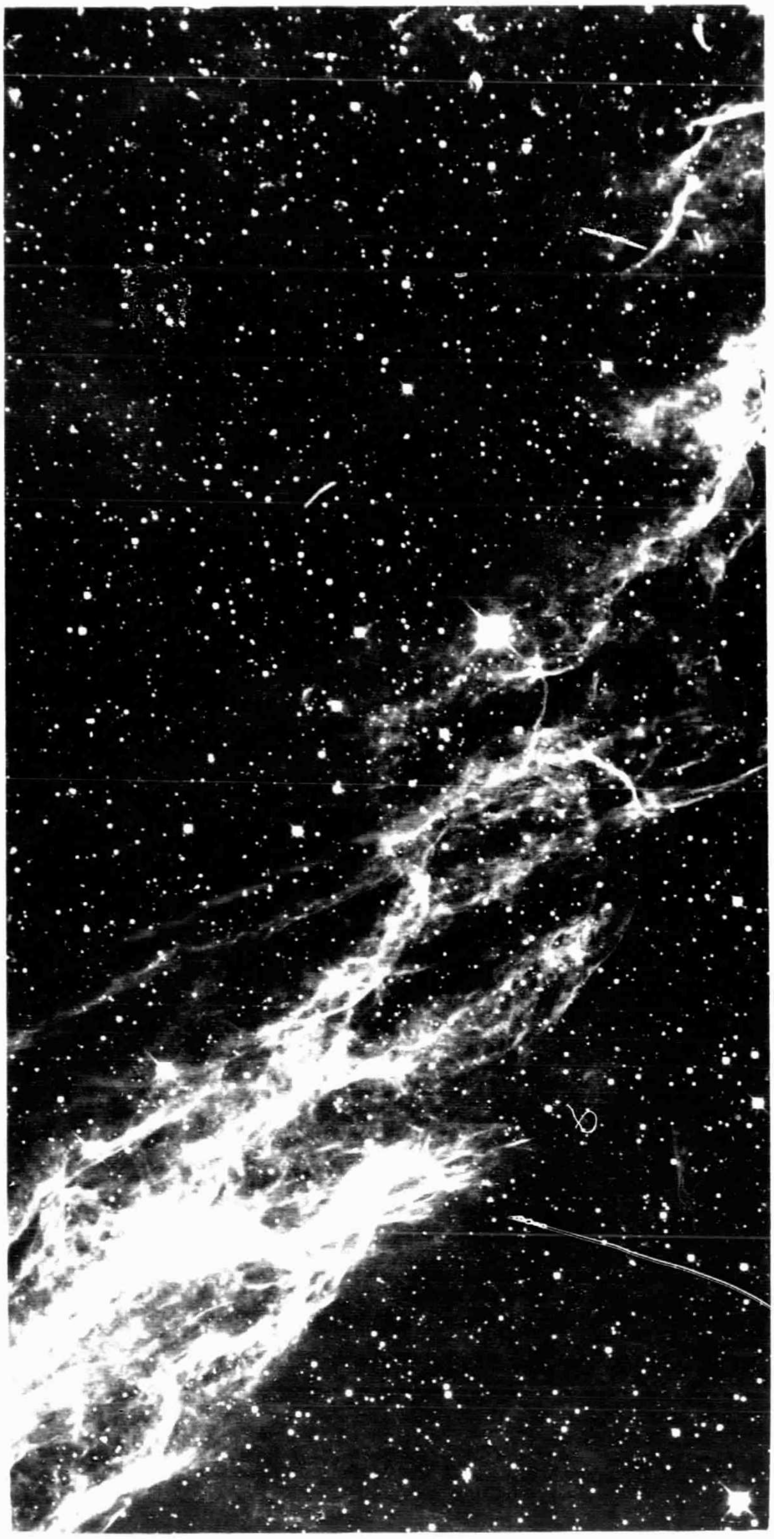

Quarterly Report No. V6092 -2

LONG RANGE PLANNING FOR SOLAR SYSTEM EXPLORATION

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Quarterly Report No. V6092 -2

LONG RANGE PLANNING FOR SOLAR SYSTEM EXPLORATION

Prepared by

Astro Sciences Center

of

IIT Research Institute
Chicago, Illinois 60616

for

Planetary Programs
National Aeronautics and Space Administration
Headquarters
Washington, D.C.

Contract No. NASW-1837

APPROVED

D L Roberts

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Astro Sciences Center

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Second Quarterly Report
Contract NASW 1837

1. INTRODUCTION

This is the second quarterly report on contract NASW 1837 and covers the period from February 1 1969 to May 1 1969. The purpose of the advanced studies is to provide an early understanding of those candidate missions, and their associated requirements, that are of importance to the long range exploration of the Solar System. A copy of the project schedule is given in Figure 1 and shows the scheduled distribution of effort between the tasks. The figures in parenthesis below each schedule is the effort actually applied to the tasks.

2. TECHNICAL PROGRESS

The following sub sections describe each of the five study tasks which have been worked on during the second quarter of the contract. Only the work performed in the second quarter is reported.

2.1 Total Scientific Objectives (J.C. Jones)

The task of collecting all the available information on theories and boundary conditions for all the planets has been completed. The data has been distilled and the objectives for exploration of the Solar System deduced.

A report has been prepared and is in the process of being reviewed internally by the Astro Sciences Center staff. Figure 2 shows a summary of the objectives, both general and specific, which have resulted from the study.

The objectives appear to show a good deal of commonality from planet to planet, especially within the grouping of "Inner Planets" and "Outer Planets".

The fact that so many of the objectives of exploration are common to a number of planets indicates the large vacuum of information that exists about the basic, important

TASK	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.
TOTAL SCIENTIFIC OBJECTIVES	2	1	2	$1\frac{1}{2}$	$\frac{1}{2}$		*				1	1	
	(1·6)	(1·1)	(1·8)	(1·5)	(0·25)	(·5)							
SPACECRAFT RADAR									1	2	2	1	*
PLANETARY ORBIT CHARACTERISTICS	1	1	1	1	1	1	1	1	1		*		
	(·85)	(·95)	(1·7)	(1·0)	(0·25)	(1·2)							
JUPITER ORBITER MISSION	1	2	2	2	$1\frac{1}{2}$	1	$1\frac{1}{2}$	2	1	1	1	2	* →
	(1·7)	(2·1)	(1·45)	(2·75)	(0·5)	—							
COMET RENDEZVOUS					1	2	2	2	1	1	1	1	* →
					(1)	(1·8)							
MISSION PLANNING		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	2	$1\frac{1}{2}$	1	1	$\frac{1}{2}$	$\frac{1}{2}$		
		(0·2)	(1·3)	(0·5)	(3·25)	(3)							
SPACECRAFT COMPARISON STUDY	2	$\frac{1}{2}$	$\frac{1}{2}$		*								
	(1·35)	(1·0)	(·4)	(·25)	(·25)	—	—						
TOTAL	6	5	6	5	5	6	6	6	5	$4\frac{1}{2}$	$5\frac{1}{2}$	5	
	(5·5)	(5·35)	(6·65)	(6·0)	△ (5·5)	(6·5)	△			△			△ Final Report

Quarterly Reports

[2] LEVEL OF EFFORT = 2mm
(2) ACTUAL EFFORT = 2mm
* TECHNICAL REPORT

FIGURE I. PROJECT SCHEDULE 1968-69.

SUMMARY OF GENERAL AND SPECIFIC OBJECTIVES

OUTER PLANETS			INNER PLANETS	
SPECIFIC OBJECTIVES	**GENERAL OBJECTIVES**	**SCIENCE AREAS**	**GENERAL OBJECTIVES**	**SPECIFIC OBJECTIVES**
	Determine the isotopic ratios H^1/H^2, He^3/He^4, Li^6/Li^7, B^{10}/B^{11}, A^{40}/A^{38}, C^{12}/C^{13}, and the abundance of Xe^{129}, K^{40} and Ne^{21}.	ISOTOPIC ABUNDANCES AND RATIOS	Determine isotopic ratios H^1/H^2, He^3/He^4, Li^6/Li^7, B^{10}/B^{11}, A^{40}/A^{38}, C^{12}/C^{13} and the abundances of X^{129}, K^{40} and Ne^{21}.	ASTEROIDS Determine the isotopic ratios Rb^{87}/Sr^{87}, Pb^{207}/Pb^{206}, and Pu^{244}.
	Determine the atmospheric abundances of H, He, Ne, H_2S, H_2O, NH_3, CH_4 and any complex organic molecules.	ELEMENTAL AND CHEMICAL ABUNDANCES AND RATIOS	Determine atmospheric abundance of N_2, A, CO_2. Determine surface abundances of O_2, Si, Fe, Al, Mg, Ca, C, K, Na.	MARS Determine the atmospheric abundances of H_2, O_2, O_3, H_2O. ASTEROIDS Determine the distribution of elemental abundances within large fragmented asteroids. VENUS Determine the atmospheric abundances of H_2O, H_2, HCl, Cl, O_3, SO_2, S, H_2S. MERCURY Determine atmospheric abundances of S, Zn, Pb, Sb.
PLUTO Determine the mineralogic composition of any solid body. COMETS Determine the mineralogical abundance of dust particles in the nucleus.		MINERALOGICAL ABUNDANCES	Determine abundance of orthoclase, plagaclase, quartz, pyroxene, olivine, amphoboles, garnets, micas.	MARS Determine abundance of limonite, hematite, calcite, goethite, siderite. VENUS Determine abundance of wollastonite, sillminite, calcite. ASTEROIDS Determine the distribution of minerals within large asteroids.
PLUTO Determine the dark and light side temperatures. COMETS Determine the thermal regime within the cometary atmosphere, and the nature of any chemical reactions occurring.	Determine the dark side temperature (at several wavelengths) and magnitude and distribution of any local thermal anomalies on the light and dark sides.	THERMAL EFFECTS	Determine the surface temperature distribution.	MARS Determine the diurnal and seasonal variations of surface temperature. VENUS Determine the mechanisms of heat transfer from the sub-solar point. VENUS Determine the cause of the high surface temperature. MERCURY Determine surface temperature regime and map local temperature anomalies.
JUPITER Determine the origin of the color of the Red Spot and the nature of its isolated location. COMETS Determine the radial velocitics of emitting radicals and their relative intensities to understand structure of cometary atmospheres.	Determine the pressure and temperature profiles and the variation of abundances with depth. Determine the vertical structure and variations in composition within the cloud system, the nature of the latitude band structure and the motions within the cloud system.	PLANETARY ATMOSPHERES	Determine the vertical profile of pressure, temperature and composition of the atmosphere.	MARS Determine the nature of the clouds and the blue haze and the circulation regime of the atmosphere. VENUS Determine the structure and composition of the cloud systems, the transmission/absorption properties of the particulates, and the circulation regime at all altitudes.
JUPITER Determine the mineralogic abundances of the outermost (retrograde) satellites. SATURN Determine the thickness of the ring system and the composition and size of the particles. PLUTO Determine the orbital perturbations with greater accuracy. COMETS Determine the orbital elements of faint comets.	Determine t[illegible] composition of any atmospheres of the satellites and the composition of any condensed materials on their surfaces.	MOTIONS AND PROPERTIES OF CONDENSED BODIES	Determine oblateness, to allow calculation of moment of inertia and hence model planet interiors.	MARS Determine the density, composition and surface structure of Phobos and Deimos. ASTEROIDS Determine the size distribution function and the spatial distribution.
PLUTO Determine the mass, diameter and oblateness of the planet. COMETS Determine the str[illegible]e and composition of the nucleus.	Determine the size of any solid body, the moment of inertia and the rotation rate. Determine if there is a core and the type of material included.	INTERNAL AND BULK PROPERTIES	Determine the density profile and the depth and nature of any phase-change and/or composition boundaries. Determine the frequency and magnitude of any internal seismic activity. Determine heat flow at surface and thermal gradient within the planet to allow estimation of magnitude and origin of internal heat sources.	
JUPITER Determine any correlation between surface features and the Red Spot. COMETS Determine the processes eroding the surface of the nucleus and the rate of erosion.	Determine the composition and phase state of any detectable surface.	SURFACE PROPERTIES	Determine topography, morphology, lithology, cratering and lineament structure of the surface.	MARS Determine the nighttime surface cooling curve to allow estimation of surface density and porosity. Determine the nature of frost deposits, including polar caps, and maria. ASTEROIDS Determine the extent of cratering and fragmentation and the nature of any debris on the surface.
COMETS Determine the interaction of the ionised cometary atmosphere with the solar wind.	Determine the type, location, and configuration of any internally produced field, and the field strength.	MAGNETIC FIELDS	Map the magnetic field in the region of interaction of the solar wind with the planet. Determine the structure and origin of any planetary magnetic field.	ASTEROIDS Measure any remnant or induced magnetism.
JUPITER Determine the origin of the decameter emission. COMETS Determine the ions released from the cometary atmosphere.	Determine the interaction of the planet with the solar wind and the density and energy distribution of any trapped particles.	CHARGED PARTICLES AND FLUX DISTRIBUTION	Map the solar plasma in the region of interaction with the planet. Determine the vertical profile, ionic species, and temperature of the ionosphere.	VENUS Determine the relationship between daytime and nighttime layers.

properties of each of the planets. Investigations up to date have been governed, inevitably, by available techniques, with little effort given to developing new techniques to provide specific pieces of information. The increase in knowledge that has been achieved by space missions is considerable only when viewed with respect to previous ignorance; when viewed alongside a listing of the total exploration objectives, as attempted here, the progress made appears less impressive. Certainly, unmanned Solar System exploration is just beginning, and it is clear that many of the objectives will be at least partially satisfied within the next two decades. What is less obvious without detailed consideration of the objectives concerned, is that large areas of basic and important information will not be satisfied unless new techniques become available either by chance or by design.

In the Science Area, "Isotopic Abundances and Ratios", for example, present interests of the scientific community, both experimentalists and theoreticians, is negligible. Theories have been generated long since, predictions made, and measurements suggested, but technological problems have prevented the collection of any data. The technical problems are certainly considerable, but similarly the data concerned is of considerable importance. Remembering that one of the overall goals of exploration is an understanding of the origin and evolution of the Solar System, isotopic data relate more directly to the early solar nebula conditions than data of any other type. Techniques are not presently available to relieve the absence of important data in this area, nor are such techniques likely to be developed easily in the near future, but the significance of the data warrants investigation of possible methods. For no matter how far exploration of the present state of the Solar System proceeds in the next decades, this data will remain the most crucial towards understanding the early, nebula state of the Solar

System.

In the Science Areas covering Elemental, Chemical and Mineralogical Abundances, techniques exist with which the relevant data can be collected, the basic problem is the one of the location at which the measurement is to be made. Abundance data on the upper atmosphere at least is available for almost all the planets. However, further data extending down to the surface are required before an understanding of the total composition and structure of the atmospheres can be achieved. Since only Mars and Mercury have visible surfaces, on all of the other planets some form of direct probing will be necessary, unless new techniques of remote abundance determination using considerably longer wavelengths can be developed. Thus, it appears that presently available methods of remote abundance determination will decrease rapidly in scientific usefulness after use on the first missions to the clouded planets. Thereafter, unless direct probing is performed or new remote techniques are utilized, understanding of the total atmosphere will depend, as it does now, on a theoretical downward extrapolation of data from the high atmosphere and continued use of existing techniques will provide decreasing scientific return.

Remote sensing techniques at longer wavelengths are also required to study the surface properties of the clouded planets and they may in addition provide information on the mineralogy and bulk properties of the non-gaseous body. Here, the method required is well known, radar. The weight of present radar systems precludes their use on space missions, but the significance and coverage of the data which only radar could provide indicates the importance of developing such systems for planetary missions, particularly the outer planets.

2.2 Planetary Orbital Characteristics (M. Hopper)

This study consists of two parts. The first part enables an experimenter to specify an "ideal" orbit or orbits for his experiment and the second part enables him to decide how well his experiment can be performed from a given orbit if certain measurement specifications are to be satisfied.

The method in each case consists of following a flow chart which is used in conjunction with parametric data and graphs relating instrument characteristics, measurement specifications, coverage characteristics and orbital parameters for each of the planets.

The method for selecting an orbit, given the instrument and the measurement specifications, is in two parts; one for experiments which make measurements of the planet surface or atmosphere, and the other for particles and fields type experiments. In the first case (near planet or planet surface measurements), it is further subdivided depending upon whether the planet rotates fast (Mars and Jupiter) or slowly (Mercury and Venus) on its axis. In the selection process a parametric set of initial orbits is considered, and as constraints are put on the desired orbit in the selection process, the less useful ones are eliminated. At the end of the procedure several useful orbits usually remain.

To date, the orbit selection method for near planet measurements has been completed and work has been started on the orbit selection method for particles and fields type experiments.

As an example of the many interrelationships involved in this process, a typical flow chart is shown in Figure 3 and a definition of input A and B follows. Each step outlines one or more charts or Tables of data specified for each planet.

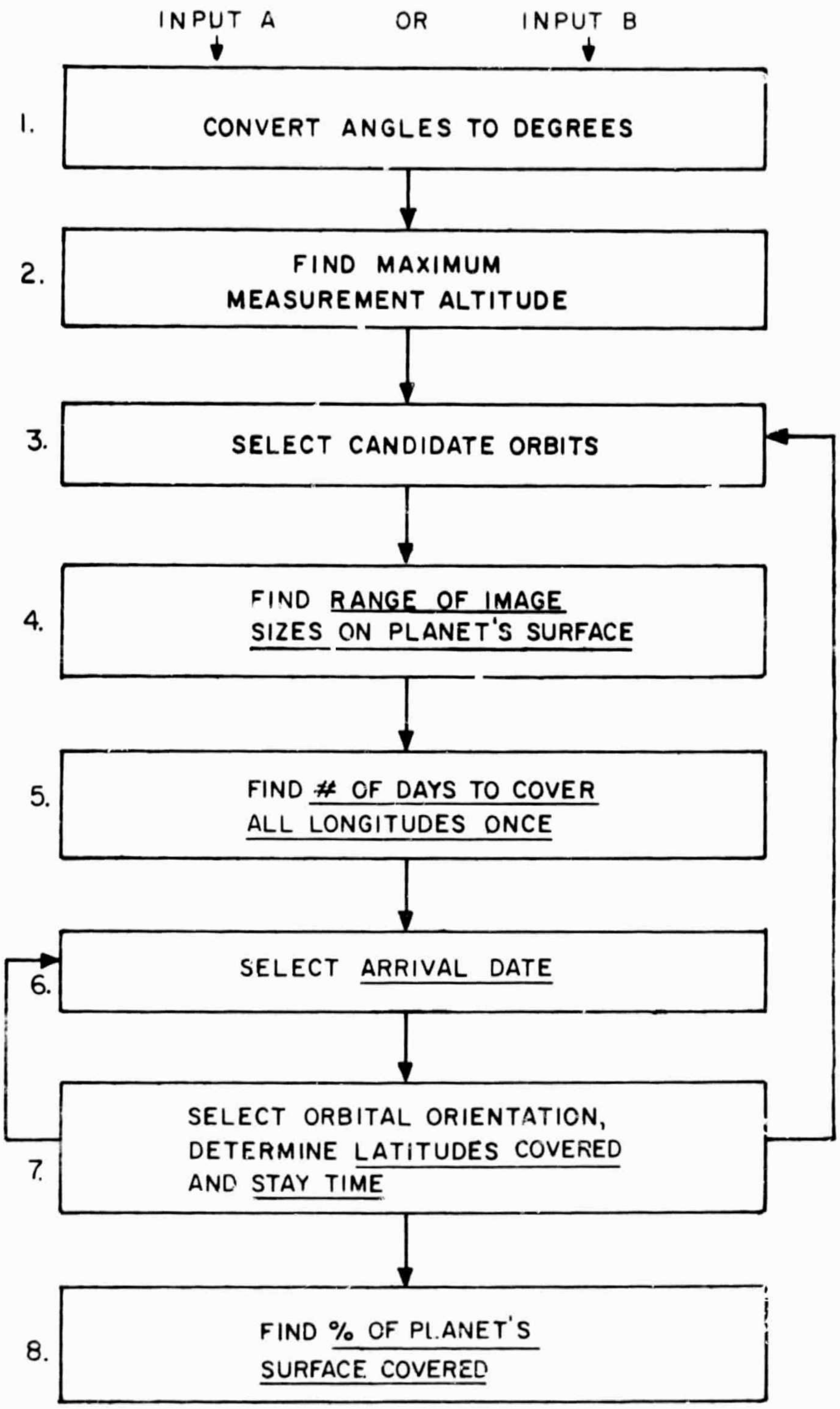

FIGURE 3. FLOWCHART FOR SELECTION OF PLANETARY ORBITS

Input A.
1. Angular resolution of sensor (AR)
2. Field of view of sensor (FOV)° or radians
3. Nadir angle of sensor (η)°
4. Ground resolution desired (CR) km
5. Longitude and latitude coverage desired
6. % overlap
7. Season
8. Solar elevation or zenith angle
9. Stay time
10. Other measurements or Sensor System design parameters

Input B.
1. Field of view of sensor (FOV)° or radians
2. Image size desired on ground (IS) km
3. Plus 5 through 10 above

2.3 Jupiter Orbiter Mission Study (John Niehoff, A. Binder, D. Klopp)

The study is concerned with the evaluation of exploration capabilities and requirements of "first generation" orbiter missions to Jupiter. The study plan is shown in Figure 4 for reference. In the last reporting period study task results were reported for "measureable selection and evaluation" and "identification of engineering objectives". During the current reporting period initial results have been obtained for "measurement techniques", "measurement specifications", "worth curves" and "Jupiter radiation belt hazards".

2.3.1 Measurement Techniques (Alan Binder, J.C. Jones)

Following definition of "first generation" measurables for Jupiter orbiter missions it is necessary to identify measurement techniques and instrument classes before specific measurement specifications can be written.

The results of this identification are presented in Figure 5. In most cases more than one measurement technique can supply information for a specific measurable. The few instances where a specific technique and instrument type per-

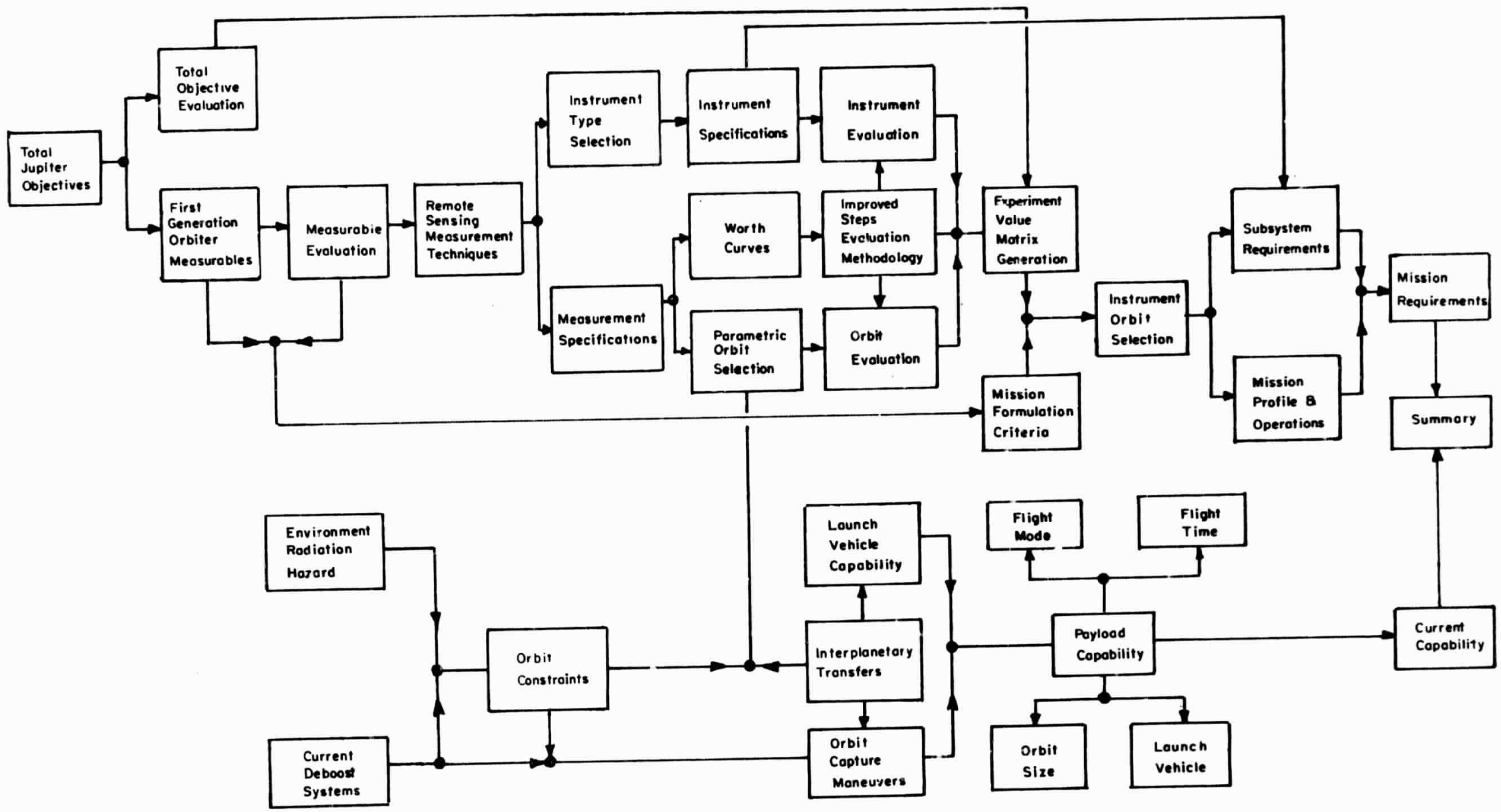

FIGURE 4. JUPITER ORBITER MISSION STUDY PLAN B - LIMITED SCOPE ESTIMATED EFFORT-18 MAN MONTHS

INSTRUMENT SELECTIONS

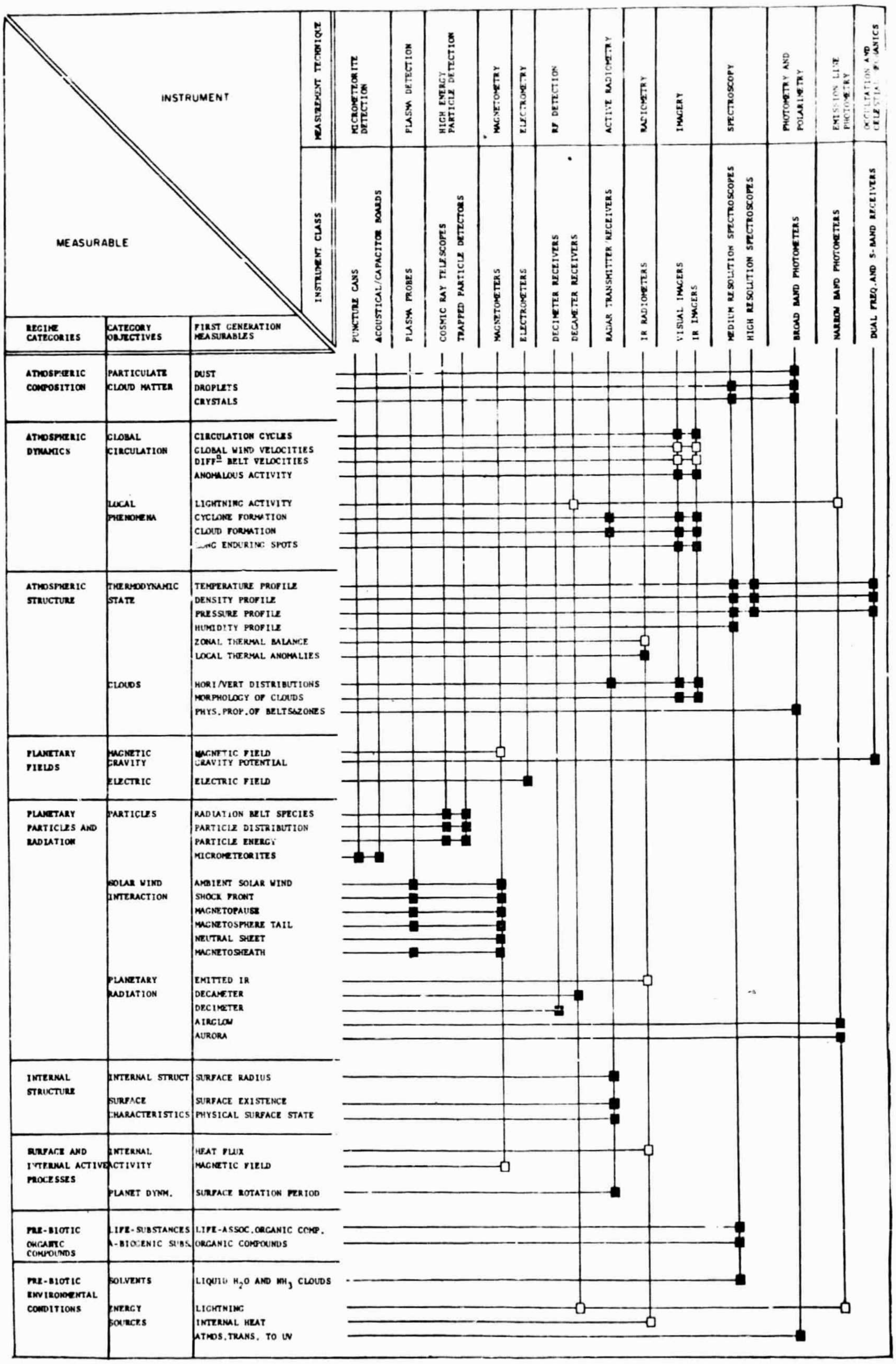

Figure 5. MEASUREMENT TECHNIQUES IDENTIFICATION

forms the same measurement under different Category Objectives are shown as open boxes in the figure.

2.3.2 Measurement Specifications and Worth Curves (Alan Binder)

Measurement specifications have been written for all of the various measurement techniques associated with each measurable as cited in Figure 5. The particular set of parameters used to characterize each measurement include the following:

Wavelength energy range
pass bands
spectral energy resolution
spatial resolution
coverage
distribution
overlap
acquisition time
repetition time
solar illumination
positional accuracy
prior measurements required

A typical example of a measurement specification is shown in Table 1 for the measurable "cyclone formation" using "imagery" as the measurement technique. A preliminary set of "worth curves" have also been generated for the measurement specifications. Worth curves are used to estimate the degradation of the measurement due to variations in the actual measurement parameters from the specifications.

2.3.3 Jupiter Radiation Belt Hazard (David A. Klopp)

The radiation belt hazard has been studied in sufficient depth to estimate spacecraft time to failure due to radiation damage caused by energetic particles trapped in the Jovian magnetosphere. Curves of radiation lifetime as a function of orbit radius similar to Figure 6 have been constructed based on certain key assumptions. For figure 6 the

TABLE 1

EXAMPLE OF MEASUREMENT SPECIFICATION DATA SHEET

MEASURABLE: Cyclone Formation

TECHNIQUE: Imagery

WAVELENGTH/ENERGY RANGE:	0.3-10μ; 5-6μ	Jovian atmosphere is probably opaque to UV below 3000 A; NH_3 and CH_4 absorb nearly completely beyond 1μ except for a clear window between 5 and 6μ
PASS BANDS:	0.5-0.7μ; 5-6μ	Visual pass band arbitrarily chosen within visual window. IR pass band uses complete window to maximize signal.
SPATIAL RESOLUTION:	10 km	Based on scale of Jovian Spots and results of TIROS photography.
COVERAGE:	5%	Estimated maximum coverage based on scale of Jovian spots.
DISTRIBUTION:	Random	Dependent on cyclone positions.
OVERLAP:	10% when applicable	Need to ensure proper registration of adjacent images.
REPETITION RATE:	Coverage of cyclone 4 times/day	Estimated to cover possible rapid developments of cyclone.
SOLAR ILLUMINATION:	Day side for visual Night side for IR	
POSITIONAL ACCURACY:	5% of frame size	To ensure accurate location.
PRIOR MEASUREMENTS:	Cyclones must be identified by regular imagery	

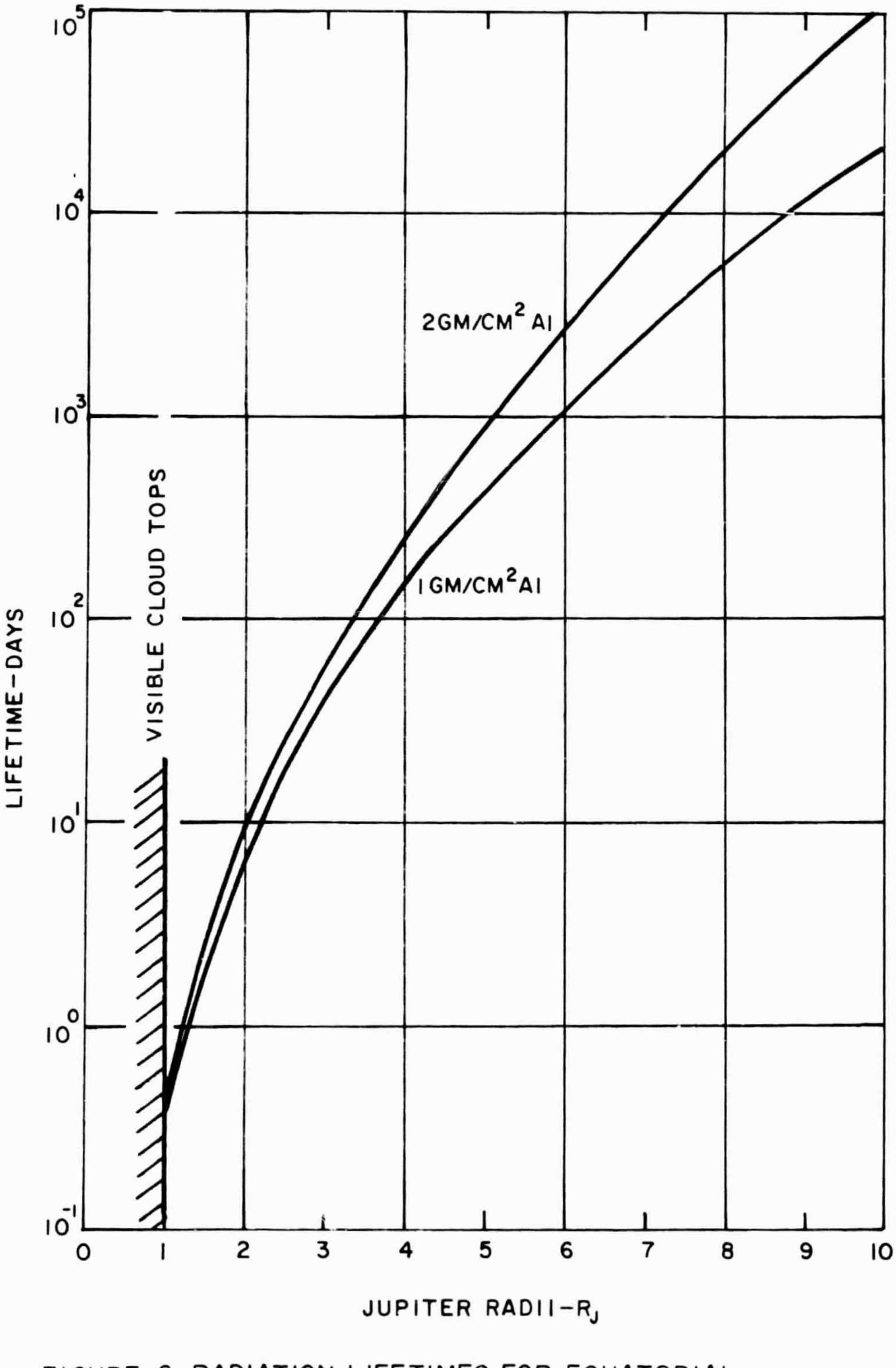

FIGURE 6. RADIATION LIFETIMES FOR EQUATORIAL JUPITER ORBITS

magnetic field has been taken as a dipole field with a field strength of 22 gauss on Jupiter's equator. The particle fluxes in the magnetosphere are regarded as limited by pitch angle diffusion (Kennel and Petschek, JGR, 71, 1-28, 1966) with an energy spectrum scaled up from Earth experience by B/L^3. The degree of saturation has been estimated by analogy with the Earth's radiation belts. The radiation damage threshold has been taken as 3×10^7 rads, corresponding to the observed damage threshold of electronic microcircuits to 3 MeV electrons. For shielding thicknesses of 1 to 2 gm/cm^2 of aluminum, virtually all the damage in the Jovian magnetosphere is due to electrons. Preliminary study also indicates that the radiation belts are likely to extend to within 200-300 km of the visible Jovian surface.

2.3.4 Study Plan

Approximately mid-way during the current reporting period the work on the Jupiter orbiter mission study was halted due to the manpower commitment to the advanced planning studies. Due to the lapse in time over which the study has been essentially dormant, to a better understanding of the study tasks and to the desire to complete the study this year, a review of of the study plan is currently under way. It appears that some measures must be taken to shorten the scope and detail of the science evaluation (through the experiment definition phase) analysis in order to complete the study. Such a decision is also indicated by the impression from the results obtained so far that the analysis as initially defined was too detailed compared to the level of current knowledge of Jupiter and spacecraft instrumentation. We are planning to have a suitably revised study schedule available by July 1, 1969.

2.4 Comet Rendezvous Study (Alan Friedlander, John Waters)

The study objectives are to identify promising comet rendezvous missions (1975-85) from the standpoint of

scientific interest and trajectory/launch vehicle requirements. Particular attention is to be given to Halley's Comet (1985 apparition) because of the timeliness of this rare opportunity. Trajectory analysis is being conducted for both the ballistic and low thrust flight modes. These will be compared on the basis of the payload flight time characteristics and the launch vehicle requirements. The ballistic mode encompasses both direct and gravity-assisted flights, and allows for one or more midcourse impulses in order to minimize the total velocity requirements. The low thrust analysis is initially treating the constant power case (nuclear-electric propulsion); solar-electric propulsion will be considered later as we acquire the necessary computational capability.

2.4.1 Ballistic Flight Mode Results

A computational procedure for generating optimum multiple impulse transfers has been developed and programmed. Results have been obtained for 2-impulse and 3-impulse transfers to Comet Encke (1980 apparition) for flight times of 1, 1.5, 2.5 and 3.5 years; these are summarized in Table 2. It is seen that the addition of a midcourse impulse reduces the total ΔV requirement in most cases, but the reduction is more significant as the flight time increases. Of the example trajectories considered, it is clear that only the 3-impulse, 3.5 year flight has a low enough ΔV requirement to allow the use of the TITAN class launch vehicle. Figure 7 illustrates the trajectory obtained for this mission. The payload capacity summarized in Table 3 shows that a spacecraft weight of 620 lbs or 1000 lbs can be delivered by the TITAN 3D/CENTAUR or TITAN 3F/CENTAUR, respectively. On this basis, it would appear that the Encke/80 mission is quite attractive providing that the 3.5 year flight time is acceptable.

A previous study by Michielsen has indicated that a rendezvous mission to Halley's comet is potentially feasible if the Jupiter gravity-assist mode is utilized. However, the

TABLE 2

SUMMARY OF BALLISTIC RENDEZVOUS TRAJECTORIES:ENCKE/80

Trajectory Type	Time of Flight(Days)	Launch Date	Arrival (Days BPH)	Total ΔV* Km/sec	Departure Impulse* Km/sec	Midcourse Impulse Km/sec	Rendezvous Impulse Km/sec
2 yr. 2 Impulse	373.5	Aug.17.3 1979	103.2	33.73	26.40	0.	7.33
1 yr. 3 Impulse	373.5	No Midcourse Impulse Indicated					
1.5 yr. 2 Impulse	543.1	Feb.26.6 1979	105.3	20.58	6.32	0.	14.26
1.5 yr. 3 Impulse	552.0	Mar. 4.4 1979	99.6	18.70	4.93	2.78	10.99
2.5 yr. 2 Impulse	900.1	Mar.8.0 1978	103.9	19.04	8.73	0	10.31
2.5 yr. 3 Impulse	901.2	Mar.8.3	102.5	15.48	5.90	1.83	7.75
3.5 yr. 2 Impulse	1276.0	Mar.1.8 1977	99.2	18.51	9.16	0.	9.35
3.5 yr. 3 Impulse	1271.1	Mar.6.35 1977	99.5	10.24	6.08	3.70	0.46

*Departure is from 100 N.M. Earth orbit (circular)

TIME OF PERIHELION = 6 December 1980

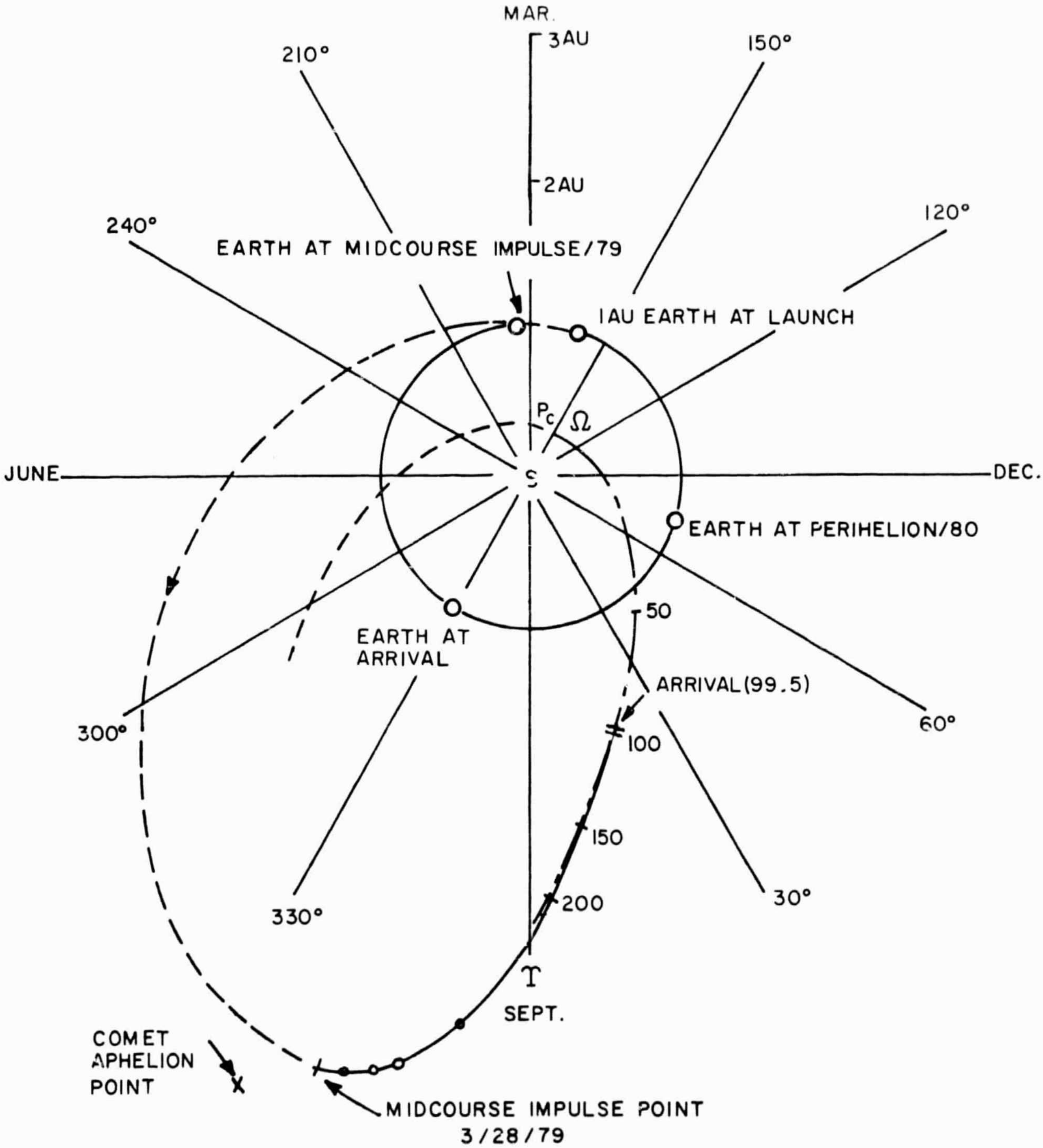

FIGURE 7. 3.5 YEAR ~3 IMPULSE MISSION TO ENCKE/80

TABLE 3

PAYLOAD CAPABILITY FOR 3.5 YEAR, 3-IMPULSE MISSION TO COMET ENCKE/80

VELOCITY REQUIREMENTS

ΔV_1 = 6/08 Km/sec (Equivalanet Launch Energy V_c = 45, 501 ft/sec)

ΔV_2 = 3.70 Km/sec

ΔV_3 = 0.46 Km/sec

ΔV guidance = 0.20 Km/sec

PROPULSION STAGE ASSUMPTIONS

ΔV_2: SPACE-STORABLE PROPELLANT, I_{sp} = 385
ΔV_3 + ΔV guidance: EARTH-STORABLE PROPELLANT, I_{sp} = 310

LAUNCH VEHICLE PERFORMANCE: OSSA ESTIMATING FACTORS AND STAGE INERT WEIGHT Handbook (1969)

LAUNCH VEHICLE / PAYLOAD	TITAN 3D/CENTAUR	TITAN3F/CENTAUR
Injected Weight	3600 lbs	5500 lbs
Delivered s/c Weight	620 lbs	1000 lbs

total ΔV requirement is about 80,000 ft/sec (launch characteristic velocity = 57,500 ft/sec; rendezvous impulse = 5.83 km/sec), which would require a launch vehicle of the SATURN/CENTAUR class. Furthermore, the trip time is almost 8 years requiring a launch in 1977 (or 1978). Preliminary results obtained from our multi-impulse program has not yet identified a ballistic trajectory opportunity which is superior to the Jupiter gravity assist mode.

2.4.2 Low Thrust Flight Mode Results

Given the comet Encke/80 opportunity which was identified by the previous ballistic analysis, it was decided to search for a low thrust flight mode utilizing the TITAN class vehicle and having a comparable payload. The trajectory and payload results for a 535 day flight are summarized by Figure 8 and Table 4. Time has not permitted a full optimization of the trajectory and vehicle parameters, so the results shown are to be considered only indicative of performance. Assuming that a nuclear-electric spacecraft having a powerplant specific mass of 55 lbs/kw were to be available for a 1979 launch, this flight mode would offer the advantage of a significantly shorter trip time compared to a ballistic flight.

Preliminary results of a low thrust rendezvous with Halley's Comet is typified by the trajectory plot shown in Figure 9. The requirements for the class of short flight times (541 days) are enormously high, and may require a launch vehicle in the Saturn class. A mission with a lower J requirement but a flight time of 950 days, is also shown. This latter trajectory is suitable for a TITAN launch vehicle.

2.5 Advanced Mission Planning

Throughout this reporting period contributions have been made to the Planetary Exploration Planning Panel (PEPP) and to the working groups set up under PEPP particularly the Outer Planets Working Group and the Mercury Working Group.

2.5.1 PEPP inputs. (David L. Roberts, William Adams, Thomas Mula)

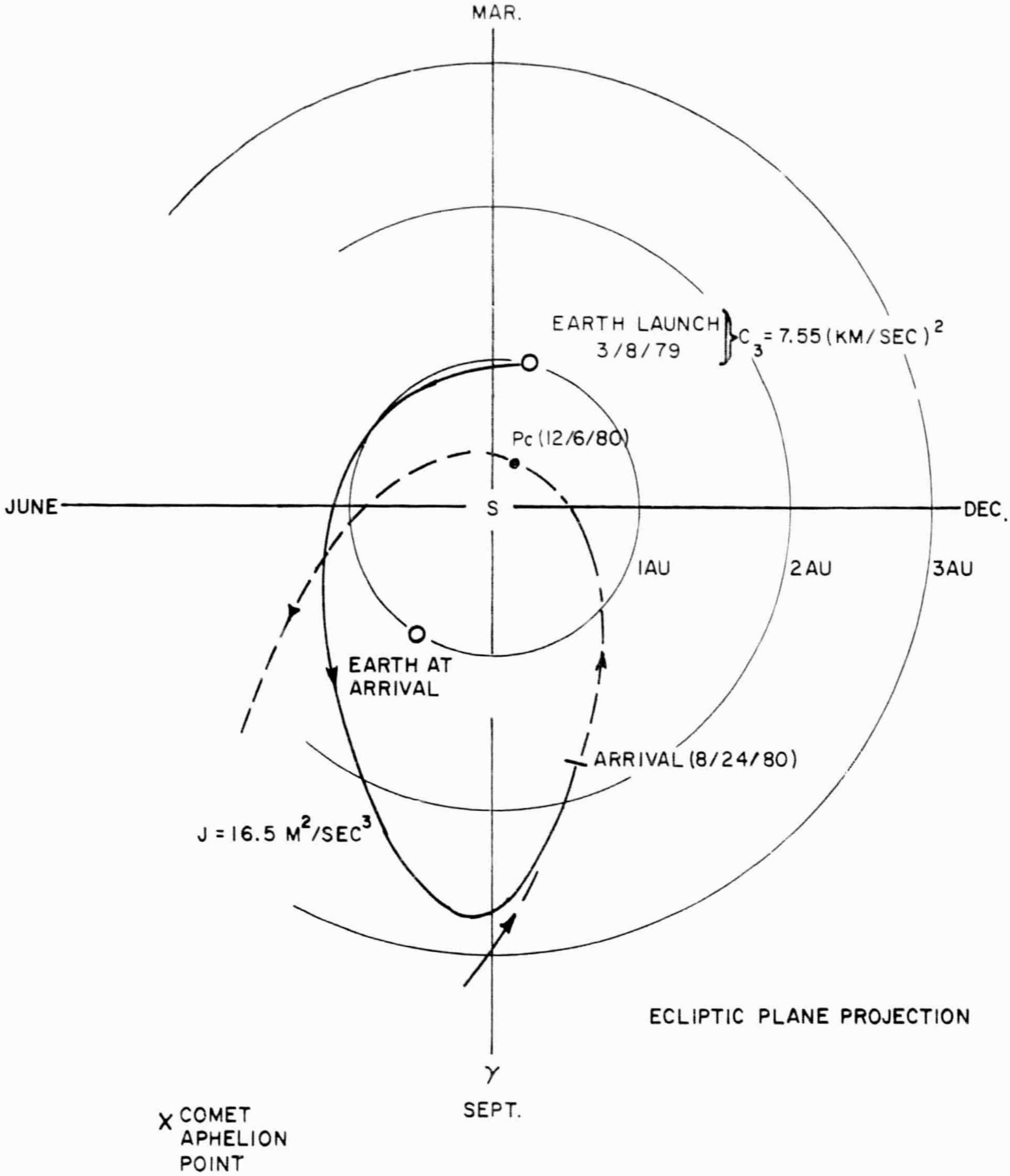

FIGURE 8. 535 DAY RENDEZVOUS MISSION TO COMET ENCKE/80
USING LOW THRUST FLIGHT MODE (NUCLEAR-ELECTRIC)

TABLE 4

ESTIMATED PAYLOAD CAPABILITY FOR
535 DAY LOW THRUST RENDEZVOUS WITH COMET ENCKE/80

CONCEPTUAL NUCLEAR-ELECTRIC SPACECRAFT

Launch Vehicle:		Titan 3D/CENTAUR
Hyperbolic Excess:		$C_3 = 7.55\ (\text{Km/sec})^2$
Power Plant:		
	Specific Mass	$= 25$ kg/kwe (55 lbs/kwe)
	Power Rating	$P_e = 77.5$ kw
	Specific Impulse	$I_{sp} = 5500$ sec
	Efficiency	$\eta = 0.71$
Total Initial Weight:		$W_o = 10{,}700$ lbs
	Power Plant:	$W_{pp} = 4280$ lbs
	Structure (8% W_o):	$W_s = 855$ lbs
	Tankage (6% W_{prop}):	$W_t = 265$ lbs
	Propellant:	$W_{prop} = 4500$ lbs

PAYLOAD INCLUDING SCIENCE, COMMUNICATIONS, GUIDANCE AND CONTROL

$W_{pl} = 800$ lbs

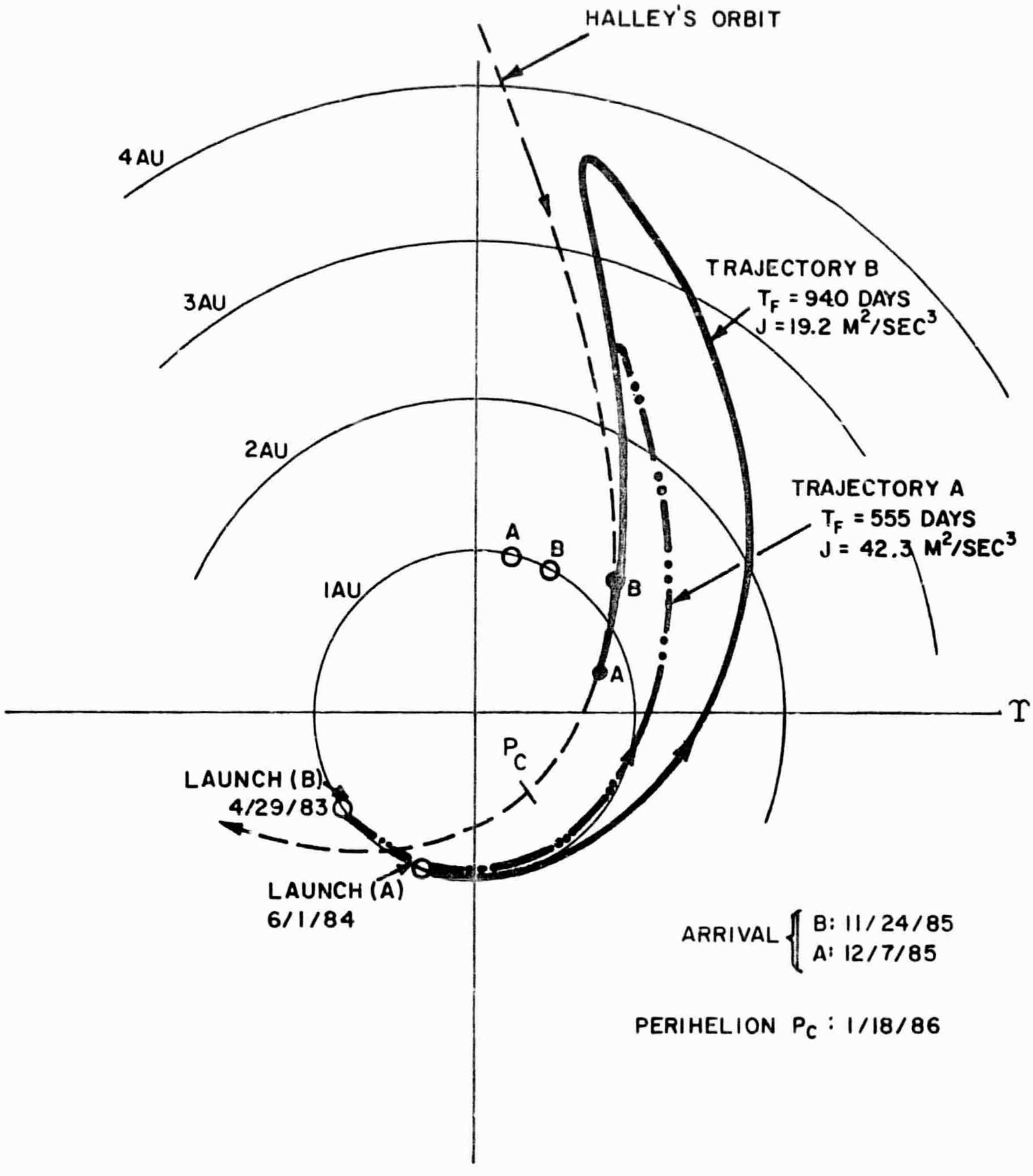

FIGURE 9. RENDEZVOUS TRAJECTORIES TO HALLEY'S COMET/85
USING LOW-THRUST FLIGHT MODE (NUCLEAR-ELECTRIC)

Contributions have been made to the generation and verification of planetary exploration options. A series of alternative exploration plans have been generated to demonstrate the major possible emphases and trade-offs in the exploration of the Solar System. For each mission included in the plans a brief definition has been provided and comparative cost estimates have been distilled from numerous independent cost submissions.

2.5.2 Outer Planet Working Group(OPWG) (John Niehoff, Martha Williams)

Three specific tasks have been performed for the OPWG during the past reporting period. These included: 1) Preliminary definition of Jupiter and Saturn Orbiter Missions, 2) Analysis of payload requirements of Galilean Satellite Orbiters and Landers and 3) Bibliography of Outer Planet Mission and Technology Studies.

A timely analysis of Jupiter and Saturn Orbiters was needed to support the planning exercises of the OPWG. Borrowing heavily from the Jupiter Orbiter Mission Study, a "quick look" analysis was performed to provide data on the type of spacecraft, payloads and orbits which would be required by "first generation" Jupiter and Saturn Orbiter Missions. The results of this task are summarized in Table 5. It should be pointed out that although the summary tends to dramatize the difference between "particle and field" and "planetology" orbiters, discussion of the results within the OPWG indicate that while logical, this separation does not appear to be essential, to a viable orbiter program.

In the course of mission selections by the OPWG it became apparent, that missions to the moons of the outer planets in the 1980-85 time period were an essential ingredient in a balanced outer planet exploration program. Accordingly, it was necessary to establish the feasibility and associated pay-

TABLE 5

SUMMARY OF JUPITER AND SATURN ORBITERS "QUICK LOOK" ANALYSIS

A numerical evaluation of science measurements indicates that first-generation Jupiter Orbiters have a potential value equivalent to approximately 30% of the total exploration of Jupiter. There are no apparent reasons why the value of first-generation Saturn Orbiter missions to exploration of Saturn should differ significantly.

Due primarily to orbit requirements and to a lesser extent stabilization requirements the science measurements reduce to just two distinct payloads

a: Particle and Field Experiments

b: Planetology (Atmosphere, Structure, and Biology) Experiments

Particle and Field Missions have the following characteristics:

Science Payload: 50 lbs
Spacecraft Weight: 425 lbs
Stabilization: Spin
Orbits: Equatorial Elliptical ($Ra/Rp \approx 20$)
Launch Vehicle Class: Titan
Flight Time: $\sim$600 days (Jupiter)
>3.5 years (Saturn)

Planetology Missions have the following characteristics:

Science Payload: 100-200 lbs
Spacecraft Weight: 1000-1250 lbs
Stabilization: 3-axis (for high resolution measurements)
Orbits: Inclined and Polar Circular (R_{max}<11 planet radii)
Launch Vehicle Class: Saturn (intermediate)
Flight Time: $\sim$800 days (Jupiter)
>4 years (Saturn)

A nuclear-electric low thrust flight mode should also be considered for the planetology orbiter. It has the advantages of a spiral circular approach permitting good opportunities for satellite observations and a 240 kw power source which would allow the addition of a radar sounding experiment.

load performance of orbiter and lander missions to at least the Galilean satellites. The payload analysis was performed for chemical, nuclear and nuclear-electric propulsion systems. Results for the lander missions are shown in Figure 10.

For the Galilean orbiter mission a 1000 lbs orbiter is conceptually possible with chemical propulsion and intermediate Saturn Launch Vehicles with 600-800 day flight times. Direct satellite approach and large two-stage retro maneuvers, however, raise serious questions about feasibility and practicality of the chemical mission mode.

Chemical propulsion Galilean Moon Lander Missions placing 1000 lbs payload on the surface are conceptually possible (excluding Io) with intermediate Saturn and Saturn V launch vehicles with flight times of around 2 years. Direct satellite approach and large two-stage capture maneuvers also question the feasibility of these missions.

A nuclear rocket retro maneuver reduces the launch vehicle requirements of the chemical propulsion lander missions somewhat. The flight time is about the same and Io landers are included. The most serious feasibility questions of this mode are the development of a small nuclear rocket stage and a guaranteed space hybernation period of about 2 years.

Nuclear-electric low thrust flight modes for the Galilean Moon 1000 lbs Lander Missions are conceptually possible with somewhat longer flight times of 2.5 to 3.5 years. There are a number of advantages to this flight mode including small Titan IIIF launch vehicles, spiral satellite approach, and a single stage solid motor braking approach stage. The primary feasibility questions center on the development of the low-thrust stage.

A bibliography of pertinent outer planet studies and a table of technology development efforts were compiled for the OPWG as evidence of background support to the various planning decisions and mission programs generated by the Group.

LAUNCH VEHICLE ASSIGNMENTS

PROPULSION	IO	EUROPA	GANYMEDE	CALLISTO
CHEMICAL	—	SATURN V CENTAUR	SATURN V	SIC · SIVB CENTAUR
NUCLEAR	SATURN V CENTAUR	SATURN V	SATURN V	SIC · SIVB CENTAUR
NUCLEAR ELECTRIC	TITAN 3F NES-B	TITAN 3F NES-B	TITAN 3F NES-B	TITAN 3F NES-B

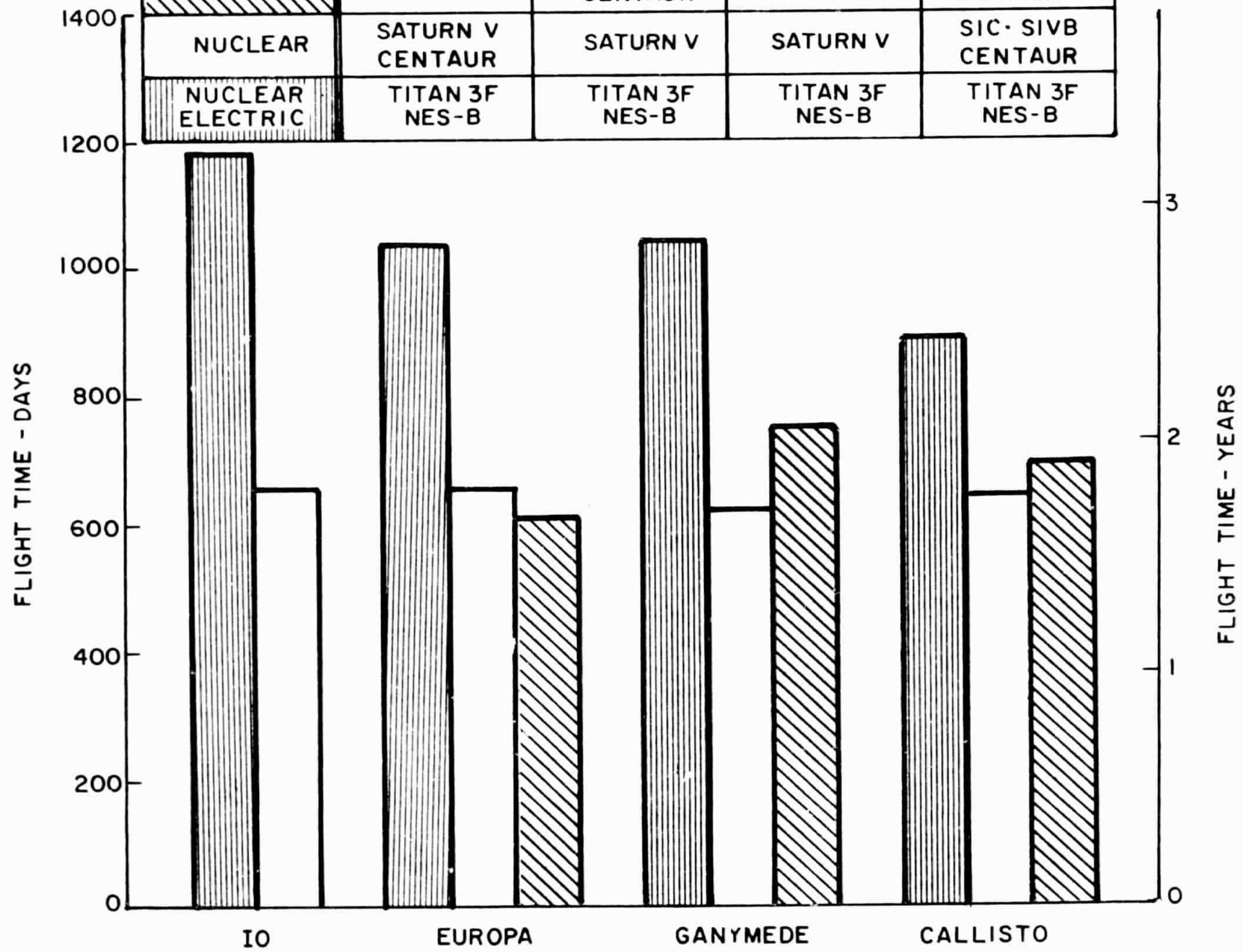

FIGURE 10. SUMMARY COMPARISONS OF FLIGHT TIME REQUIREMENTS FOR LANDING 1000 LBS. PAYLOAD ON THE GALILEAN MOONS OF JUPITER USING CHEMICAL, NUCLEAR AND NUCLEAR-ELECTRIC PROPULSION.

The bibliography of pertinent studies is tabulated chronologically by publication date within the following categories:

I. Program Planning and Status
II. Objectives and Environment
III. Mission Analysis
IV. Systems Requirements and Operations
V-VIII. Trajectories

The bibliography should be rather complete with approximately 125 entries dating back as far as 1965. Some effort was made to limit the number of system requirements references to general survey-type entries. Also no reports dealing with specific design of spacecraft experiments (e.g. Pioneer F&G category I proposals) have been included.

The table summarizing the status of critical technology development at the NASA Centers was constructed from inputs by Paul Tarver and responses of Group members.

3. OVERALL PERFORMANCE

The performance of tasks in the second quarter has occupied the scheduled effort. However, the emphasis has been changed somewhat by the accelerated effort placed on the advanced mission planning task at the expense of the Jupiter orbiter study. Largely as a result of this, and on account of the early need for results on the Jupiter orbiters, it is intended to review and possibly curtail the detailed measurement phase of the Jupiter study. One new task will be started in the next quarter: spacecraft radar. This will replace the Total Objectives study which has been completed.